International Journal of

Rock Mechanics and Mining Sciences

Volume 30 1993

List of Contents and Author Index

Editor-in-Chief:
J. A. Hudson, Imperial College, London, UK

Pergamon Press
Oxford New York Seoul Tokyo

Rock Mechanics and Mining Sciences

Editor-in-Chief

Professor J. A. Hudson
7 The Quadrangle
Welwyn Garden City
Herts AL8 6SG, U.K.

Editorial Advisors

Professor W. F. Brace
Department of Earth & Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, U.S.A.
Professor E. T. Brown
Faculty of Engineering, University of Queensland, St Lucia, Queensland 4072, Australia.
Professor N. G. W. Cook
Department of Materials Science and Engineering, University of California, Hearst Mining Building, Berkeley, CA 94720, U.S.A.
Professor C. Fairhurst
Department of Civil and Mineral Engineering, 122 Civil and Mineral Engineering Building, 500 Pillsbury Drive S.E., University of Minnesota, Minneapolis, MN 55455-0220, U.S.A.
Professor R. E. Goodman
Department of Civil Engineering, University of California, Davis Hall, Berkeley, CA 94720, U.S.A.
Professor E. Hoek
West Broadway Professional Centre, 412-2150 West Broadway, Vancouver, BC, Canada V6K 4L9.

Editorial Board

Professor G. Barla
Department of Structural Engineering, Technical University (Politecnico) of Turin, Corso Duca delgi Abruzzi 24, 10129 Torino, Italy.
Dr B. H. G. Brady
Dowell Schlumberger Inc., P.O. Box 2710, Tulsa, OK 74101, U.S.A.
Dr F. H. Cornet
Institut de Physique du Globe, Université Pierre et Marie Curie, 4 place Jussieu, 75230 Paris Cedex 05, France.
Professor S. L. Crouch
Department of Civil and Mineral Engineering, 122 Civil and Mineral Engineering Building, 500 Pillsbury Drive S.E., University of Minnesota, Minneapolis, MN 55455-0220, U.S.A.
Professor Y. D. Diadkin
G. V. Plekhanov Mining Institute, St Petersburg V-26, 21 Liniya 2, Russia.
Professor H. K. Kutter
Ruhr-Universität Bochum, Institut für Geologie, 463 Bochum, Universitätsstrasse 150, Germany.
Dr P. R. La Pointe
Golder Associates, 4104-148th Avenue NE, Redmond, WA 98052, U.S.A.
Professor N. R. Morgenstern
Department of Civil Engineering, University of Alberta, Edmonton, Alberta, Canada T6G 2E1.
Professor Y. Nishimatsu
Department of Mineral Development Engineering, University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo 113, Japan.
Professor W. G. Pariseau
Department of Mining Engineering, University of Utah, 318 W. C. Browning Building, Salt Lake City, UT 84112, U.S.A.
Professor F. F. Roxborough
School of Mining Engineering, University of New South Wales, P.O. Box 1, Kensington, New South Wales 2033, Australia.
Professor O. Stephansson
Department of Engineering Geology, Royal Institute of Technology, S-100 44 Stockholm, Sweden.
Professor T. K. Tan
Institute of Geophysics, Academia Sinica, Beijing, China.
Dr H. Wagner
Chamber of Mines, P.O. Box 809, Johannesburg 2000, South Africa.

Geomechanics Abstracts

Editor

Dr D. H. Spencer

Editorial Director

Professor J. A. Hudson
Rock Mechanics Information Service
Imperial College of Science, Technology and Medicine,
Royal School of Mines, Prince Consort Road,
London SW7 2BP, U.K.
Tel. 071-589-5111 extn 6436
Fax. 071-589-6806
Telex 929484

Geomechanics Literature Search Service

The Rock Mechanics Information Service will carry out retrospective information searches on request. This search will encompass the GeoMechanics Abstracts database (see below) which covers all material published in the *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts* since 1977 and other material published in its original form before and since this date. Other databases may also be searched on request. Initial enquiries may be made by telephone, fax, post or telex. Search requests can be in the requester's own terms or as a list or combination of keywords. Background information on the project requiring the search is also useful. The cost of this service is £40 per search topic plus £0.45 per printed reference (at 12/1989). VAT or airmail postage will be added where applicable. Enquiries should be addressed to the **Rock Mechanics Information Service** at the above address.

Geomechanics Abstracts Data Base

The GeoMechanics Abstracts database (GMA), one of the many available online from the ORBIT Search Service Division of InfoPro Technologies Ltd, covers the fields of rock mechanics, soil mechanics, and engineering geology, plus the many closely related disciplines. GMA is available to the public for literature searching.

For further details please contact the ORBIT Search Service (addresses given on p. *ii* of the Geomechanics Abstracts in this issue).

Published 7 issues/annum in February, April, June, August, October and December

Copyright © 1993 Pergamon Press Ltd

Publishing office: Pergamon Press Ltd, Pergamon House, Bampfylde Street, Exeter EX1 2AH, U.K. (*Tel.* (0392) 51558; *Fax* 425370).

Production Editor: Alison J. Snell.

Subscription and advertising offices: Enquiries from customers in North America should be sent to Pergamon Press Inc., 660 White Plains Road, Tarrytown, NY 10591-5153, U.S.A.; and from the rest of the world to Pergamon Press Ltd, Headington Hill Hall, Oxford OX3 0BW, U.K. (*Tel.* (0865) 794141).

Annual subscription rates: Annual Institutional Subscription Rates 1994: North, Central and South America, U.S.$845.00; Rest of World, £550.00. Associated Personal Subscription Rates are available on request for those whose institutions are library subscribers. Sterling prices exclude VAT. Non-VAT registered customers in the European Community will be charged the appropriate VAT in addition to the price listed. Prices include postage and insurance and are subject to change without notice. *Note*: frequency reverts to 6 issues/annum in 1994.

Back issues: Back issues of all previously published volumes, in both hard copy and on microform, are available direct from Pergamon Press.

Second class postage paid at RAHWAY NJ. Postmaster send address corrections to *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, c/o Pergamon Press Inc., 660 White Plains Road, Tarrytown, NY 10591-5153, U.S.A.

CONTENTS OF VOLUME 30

NUMBER 1

J. A. Hudson	I	Editorial
K. Masuda, O. Nishizawa, K. Kusunose and T. Satoh	1	Laboratory study of effects of *in situ* stress state and strength on fluid-induced seismicity
S. J. D. Cox and P. G. Meredith	11	Microcrack formation and material softening in rock measured by monitoring acoustic emissions
P. M. C. B. M. Cools	25	Temperature measurements upon the chisel surface during rock cutting
L. Zhang and J. A. Franklin	37	Prediction of water flow into rock tunnels: an analytical solution assuming an hydraulic conductivity gradient
T. Hashida and H. Takahashi	47	Significance of AE crack monitoring in fracture toughness evaluation and non-linear rock fracture mechanics
T. Hashida	61	Fracture toughness testing of core-based specimens by acoustic emission
Geomechanics Abstracts	1A	

NUMBER 2

Z. Ouyang and D. Elsworth	71	Evaluation of groundwater flow into mined panels
T. Papaliangas, S. R. Hencher, A. C. Lumsden and S. Manolopoulou	81	The effect of frictional fill thickness on the shear strength of rock discontinuities
R. L. McNearny and J. F. Abel Jr	93	Large-scale two-dimensional block caving model tests
K. Kuriyama and Y. Mizuta	111	Three-dimensional elastic analysis by the Displacement Discontinuity Method with boundary division into triangular leaf elements
N. D. Cristescu	125	A general constitutive equation for transient and stationary creep of rock salt
H. C. M. Chan	141	Fracture mechanics analysis of the North West Fault Block of the Prudhoe Bay Field
Technical Notes		
H. R. G. K. Hack, J. Hingira and W. Verwaal	151	Determination of discontinuity wall strength by Equotip and ball rebound tests
C. Butenuth, M. H. de Freitas, D. Al-Samahiji, H. D. Park, J. W. Cosgrove and K. Schetelig	157	Observations on the measurement of tensile strength using the hoop test
V. N. Kazakidis and M. S. Diederichs	163	Understanding jointed rock mass behaviour using a ubiquitous joint approach
H. Nagahama and K. Yoshii	173	Fractal dimension and fracture of brittle rocks
Geomechanics Abstracts	71A	

NUMBER 3

F. Guo, N. R. Morgenstern and J. D. Scott — 177 An experimental investigation into hydraulic fracture propagation—Part 1. Experimental facilities

F. Guo, N. R. Morgenstern and J. D. Scott — 189 An experimental investigation into hydraulic fracture propagation—Part 2. Single well tests

F. Guo, N. R. Morgenstern and J. D. Scott — 203 An experimental study of well communication by hydraulic fracturing

M. H. Leite, B. Ladanyi and D. E. Gill — 219 Determination of creep parameters of rock salt by means of an *in situ* sharp cone test

Yu. N. Gordeyev — 233 Growth of a crack produced by hydraulic fracture in a poroelastic medium

P. A. Hart — 239 Foundation behaviour in reusable tunnels in weak rocks

S. Okubo, K. Fukui and Y. Nishimatsu — 247 Control performance of servo-controlled testing machines in compression and creep tests

X. Huang, B. C. Haimson, M. E. Plesha and X. Qiu — 257 An investigation of the mechanics of rock joints—Part I. Laboratory investigation

X. Qiu, M. E. Plesha, X. Huang and B. C. Haimson — 271 An investigation of the mechanics of rock joints—Part II. Analytical investigation

D. R. Schmitt and M. D. Zoback — 289 Infiltration effects in the tensile rupture of thin walled cylinders of glass and granite: implications for the hydraulic fracturing breakdown equation

V. Mlakar, F. P. Hassani and M. Momayez — 305 Crack development and acoustic emission in potash rock

Technical Note

R. M. Göktan and C. Ayday — 321 A suggested improvement to the Schmidt rebound hardness ISRM suggested method with particular reference to rock machineability

Discussion

E. Detournay and T. J. Boone — 322 Discussion of a paper by M. S. Bruno and F. M. Nakagawa "Pore pressure influence on tensile fracture propagation in sedimentary rock"

139A Geomechanics Abstracts

NUMBER 4

W. Z. Savage — 325 Gravity-induced stresses near a vertical cliff

A. Zang and H. Berckhemer — 331 Classification of crystalline drill cores from the KTB deep well based on strain, velocity and fracture measurements

H. Xie and W. G. Pariseau — 343 Fractal character and mechanism of rock bursts

M. Cai and H. Horii — 351 A constitutive model and FEM analysis of jointed rock masses

W. Steiner	361	Swelling rock in tunnels: rock characterization, effect of horizontal stresses and construction procedures
K. X. Hu and Y. Huang	381	Estimation of the elastic properties of fractured rock masses
R. Corthésy, D. E. Gill and M. H. Leite	395	An integrated approach to rock stress measurement in anisotropic non-linear elastic rock
W. L. Fourney, R. D. Dick, X. J. Wang and Y. Wei	413	Fragmentation mechanism in crater blasting
X. L. Yao, D. J. Reddish and B. N. Whittaker†	431	Non-linear finite element analysis of surface subsidence arising from inclined seam extraction
Technical Notes		
M. M. Yeşil, A. G. Paşamehmetoğlu and T. Bozdağ	443	A triaxial swelling test apparatus
J. F. Labuz and J. M. Bridell	451	Reducing frictional constraint in compression testing through lubrication
J. A. Hudson and J. L. Hudson	457	Establishing potential behavioural modes of rock engineering systems by computer simulation of interaction matrix energy flux
H. Nagahama	469	Fractal fragment size distribution for brittle rocks
Cai Sijing, Tong Guangxu and Gao Hualin	473	Grey system theory applied to rock mechanics
Geomechanics Abstracts	207A	

NUMBER 5

P. H. S. W. Kulatilake, S. Wang and O. Stephansson	479	Effect of finite size joints on the deformability of jointed rock in three dimensions
P. H. S. W. Kulatilake, D. N. Wathugala and O. Stephansson	503	Joint network modelling with a validation exercise in Stripa mine, Sweden
F. Homand, E. Morel, J.-P. Henry, P. Cuxac and E. Hammade	527	Characterization of the moduli of elasticity of an anisotropic rock using dynamic and static methods
W. Zhu and P. Wang	537	Finite element analysis of jointed rock masses and engineering application
Technical Notes		
W. Zhu, Z. Liang and J. Xu	545	Physical simulation tests on jointed rock and strength prediction
N. Kato, K. Yamamoto, H. Yamamoto and T. Hirasawa	551	A stress-corrosion model for strain-rate dependence of the frictional strength of rocks
Z. Şen	555	RQD-fracture frequency chart based on a Weibull distribution
R. D. Carroll	559	A vacuum hammer seismic source for underground use

M. B. Reed, P. Grasso, D. Rizzi and G. Rabajoli 567 Improvement of rock properties by bolting in the plastic zone around a tunnel: a numerical study

Discussion
B. Ladanyi 573 Discussion of a paper by S. Yazici and P. K. Kaiser "Bond strength of grouted cable bolts"

Geomechanics Abstracts 269A

NUMBER 6

R. D. Carroll and J. W. LaComb 575 Borehole techniques identifying subsurface chimney heights in loose ground—some experiences above underground nuclear explosions

M. W. F. Grabinsky and J. H. Curran 591 Efficient mesh generation procedures for finite element analysis of underground structures

G. Li and K. H. R. Moelle 601 A compliance technique for the determination of crack lengths in heterogeneous and brittle sandstones

F. Guo, N. R. Morgenstern and J. D. Scott 617 Interpretation of hydraulic fracturing breakdown pressure

Technical Notes
F. Guo, N. R. Morgenstern and J. D. Scott 627 Interpretation of hydraulic fracturing pressure: a comparison of eight methods used to identify shut-in pressure

J. Zhao and C. P. Tso 633 Heat transfer by water flow in rock fractures and the application to hot dry rock geothermal systems

Y. Zhao, J. Huang and R. Wang 643 Real-time SEM observations of the microfracturing process in rock during a compression test

D. Song 653 Non-linear viscoplastic creep of rock surrounding an underground excavation

W. Verwaal and A. Mulder 659 Estimating rock strength with the Equotip Hardness Tester

L. L. Mishnaevsky Jr 663 A brief review of Soviet theoretical approaches to dynamic rock failure

Geomechanics Abstracts 333A

NUMBER 7

ROCK MECHANICS IN THE 1990s

Preface *B. C. Haimson* xiii

Experimental Techniques and Laboratory Investigations

Mechanical properties and microstructure of shock-conditioned tuff—*J. W. Martin, J. T. Fredrich, C. W. Felice and S. J. Green* 669

Empirical relations between compressive strength and porosity of siliciclastic rocks—*L. Vernik, M. Bruno and C. Bovberg* 677

Advanced triaxial swelling tests on preserved shale cores—*R. P. Steiger* 681

Measurement of the stress corrosion limit (K_0) in quartz and Na-lime glass—*J. Dunning, S. K. McDonald, B. J. Douglas and C. Dintaman* 687

Pore geometry and transport properties of Fontainebleau sandstone—*J. T. Fredrich, K. H. Greaves and J. W. Martin* 691

PEAK: a new kind of surface microscope—*W. B. Durham and B. P. Bonner* 699

Shale strength measurements using a penetrometer—*M. E. Chenevert and V. Dwarakanath* 703

The Rock Fracture Hammer for indexing the impact strength of rocks in mechanical excavation—*H. I. Inyang and J. M. Pitt* 707

Tensile stress–strain behavior of lightly cemented sand—*R. N. Dass, S. C. Yen, V. K. Puri, B. M. Das and M. A. Wright* 711

Normalized rock failure envelope as a function of rock grain size—*G. Hareland, C. E. Polston and W. E. White* 715

Constitutive mechanical behaviour of synthetic sandstone formed under stress—*R. M. Holt, T. E. Unander and C. J. Kenter* 719

Experimenal deformation of shale: mechanical properties and microstructural indicators of mechanisms—*W. D. Ibanez and A. K. Kronenberg* 723

Dilatancy of rock salt in laboratory tests—*L. L. Van Sambeek, J. L. Ratigan and F. D. Hansen* 735

Fabric evolution during the deformation of chalk—*N. M. Kågeson-Loe, M. E. Jones, D. N. Petley and M. J. Leddra* 739

Physical modeling of piers socketed into soft rocks—*A. R. Khan and B. Amadei* 747

Geophysical Properties of Rocks

Compressional to shear velocity ratios in sedimentary rocks—*J. E. Johnston and N. I. Christensen* 751

Shear wave attenuation in dry and saturated sandstone at seismic to ultrasonic frequencies—*D. H. Green, H. F. Wang and B. P. Bonner* 755

Acoustic velocity changes during shear enhanced compaction of sandstone—*T. E. Scott Jr, Q. Ma and J.-C. Roegiers* 763

Modulus and permeability variations during air/water flow in shaley sandstones—*J. Holder, S. Thallak, M. J. Younus and K. E. Gray* 771

Variation of shear-wave amplitude during frictional sliding—*W.-Y. Chen, C. W. Lovell, G. M. Haley and L. J. Pyrak-Nolte* 779

Effects of stress anisotropy on the static and dynamic properties of Berea sandstone—*S. L. Ita, N. G. W. Cook, L. R. Myer and K. T. Nihei* 785

Analysis of induced seismicity for fault zone identification—*F. H. Cornet and O. Scotti* 789

Potential role of acoustic emission/microseismicity investigations in the site characterization and performance monitoring of nuclear waste repositories—*R. P. Young and C. D. Martin* 797

Critical porosity—a physical boundary in poroelasticity—*H. Yin, A. Nur and G. Mavko* 805

Rock Fractures and Joints

Modeling borehole breakout by mixed mode crack growth, interaction, and coalescence—*W. Du and J. M. Kemeny* 809

A model of crack growth in microcracked rock—*A. V. Dyskin and L. N. Germanovich* 813

The Cracked Chevron Notched Brazilian Disc test—geometrical considerations for practical rock fracture toughness measurement—*R. J. Fowell and C. Xu* 821

Assessment of conventional methodologies for joint roughness coefficient determination—*S. M. Hsiung, A. Ghosh, M. P. Ahola and A. H. Chowdhury* 825

The pressure dependence of apparent hydrofracture toughness—*S. Thallak, J. Holder and K. E. Gray* 831

Determination of *in situ* fracture toughness—*X. L. Zhao and J.-C. Roegiers* 837

A study of squeezing flow in fracture channels—*D. Lin and J.-C. Roegiers* 841

Hydromechanical response of a fracture undergoing compression and shear—*W. A. Olsson and S. R. Brown* 845

Laboratory study of water flow through multiple fractures—*M. Shimo and S. Iihoshi* 853

Stability of the jointed roof in stratified rock—*E. K. S. Passaris, J. Q. Ran and P. Mottahed* 857

Numerical analysis of mixed Mode I and Mode II fracture propagation—*B. Shen and O. Stephansson* 861

Effect of strain rate on a set of fractures—*H. Wu and D. D. Pollard* 869

Fracture nucleation from a compression-parallel, finite-width elliptical flaw—*Y. G. Yuan, E. Z. Lajtai and M. L. Ayari* 873

Fractal characteristics of mesofractures in compressed rock specimens—*Y. Zhao, J. Huang and R. Wang* 877

Acoustic Emission and Failure Prediction

The role of acoustic emission in the study of rock fracture—*D. Lockner* 883

Acoustic emission and ultrasonic velocity study of excavation-induced microcrack damage at the Underground Research Laboratory—*S. R. Carlson and R. P. Young* 901

Studying hydraulic fracturing mechanism by laboratory experiments with acoustic emission monitoring—*I. Matsunaga, H. Kobayashi, S. Sasaki and T. Ishida* 909

Precursory pressure anomalies prior to coal mine failures—*B. T. Brady and K. Hanna* 913

Patterns of microseismic activity prior to a mountain bump—*J. P. Coughlin and G. A. Rowell* 917

The development of rock fracture from microfracturing to main fracture formation—*J. Huang, Z. Wang and Y. Zhao* 925

General theory of the Kaiser effect—*D. J. Holcomb* 929

Anisotropic crack damage and stress-memory effects in rocks under triaxial loading—*C. E. Stuart, P. G. Meredith, S. A. F. Murrell and J. G. van Munster* 937

Assessment of damage in rock by using the Kaiser effect of acoustic emission—*C. Li and E. Nordlund* 943

The effect of attenuation of b-values in acoustic emission measurements—a theoretical investigation—*T. E. Unander* 947

In Situ Stress Measurements

In situ stress measurement by hydraulic fracturing at the Kamaishi mine—*K. Hayashi and T. Ito* 951

Estimating the state of stress from subhorizontal hydraulic fractures at the Underground Research Laboratory, Manitoba—*B. Haimson, M. Lee, N. Chandler and D. Martin* 959

Near-surface, "thin skin" reverse faulting stresses in the southeastern United States—*D. Moos and M. D. Zoback* 965

Hydrofrac stress data for the European HDR Research Project Test Site Soultz-sous-Forets—*G. Klee and F. Rummel* 973

In situ stress measurements and their application in the design of the Gjøvik Olympic Mountain Hall—*L. W. Tunbridge, S. E. Hansen and J. Kristiansen* 977

Studies on hydraulic fracturing stress measurement assisted by water jet borehole slotting—*Y. Mizuta, S. Kikuchi and K. Tokunaga* 981

Influence of a stress relief hole's depth on induced displacements: application in interferometric stress determinations—*D. R. Schmitt and Y. Li* 985

Bored raise overcoring for *in situ* stress determination at the Underground Research Laboratory—*N. A. Chandler* 989

Stress heterogeneity and geological structures—*C. D. Martin and N. A. Chandler* 993

Rock stress redistribution around an open pit mine in hardrock—*A. Myrvang, S. E. Hansen and T. Sørensen* 1001

Gravitational stresses in long asymmetric ridges and valleys in anisotropic rock—*E. Pan and B. Amadei* 1005

Variability and quality in ASR data represented by the Sandia Model—*S. Butterworth and P. W. Burton* 1009

In situ stress heterogeneity and crack density distribution—*R. Ikeda* 1013

Three-dimensional *in situ* stress determination by anelastic strain recovery of a rock core—*K. Matsuki and K. Takeuchi* 1019

Differential strain curve analysis to estimate the stress state of the Hijiori hot dry rock field, Japan—*Y. Oikawa, I. Matsunaga and T. Yamaguchi* 1023

Borehole Instability and Breakouts

The role of the intermediate principal stress in wellbore stability studies: evidence from hollow cylinder tests—*M. A. Addis and B. Wu* 1027

Effects of deformation and strength anisotropy on borehole failures in saturated shales—*T. Aoki, C. P. Tan and W. E. Bamford* 1031

Compressive and tensile failure of boreholes arbitrarily-inclined to principal stress axes: application to the KTB boreholes, Germany—*M. Brudy and M. D. Zoback* 1035

Laboratory study of borehole breakouts in Lac du Bonnet granite: a case of extensile failure mechanism—*M. Lee and B. Haimson* 1039

Laboratory study of borehole breakouts in Cordova Cream: a case of shear failure mechanism—*B. C. Haimson and I. Song* 1047

Solution for pore pressure and stress in a porous hollow cylinder: application to a laboratory experiment—*D. R. Schmitt, R. J. Tait and H. Spann* 1057

Yield and closure of directional and horizontal wells—*R. T. Ewy* 1061

Influence of anisotropies in borehole stability—*S. H. Ong and J.-C. Roegiers* 1069

The influence of rock anisotropy on borehole breakouts: a microstatistical approach—*F. D. E. Cuisiat and J. A. Hudson* 1077

The effect of anisotropic stress state on the stability of perforation cavities—*J. Tronvoll, N. Kessler, N. Morita, E. Fjær and F. J. Santarelli* 1085

X-Ray tomography studies of wellbore processes under *in situ* stress conditions—*J. M. Cook, G. Goldsmith and F. Auzerais* 1091

A new hypothesis to explain stability of borehole breakouts—*J. B. Cheatham Jr* 1095

An analytical method for determining horizontal stress bounds from wellbore data—*C. P. Tan, D. R. Willoughby, S. Zhou and R. R. Hillis* 1103

Crustal stresses in the North Sea from breakouts and other borehole data—*S. M. Cowgill, P. G. Meredith, S. A. F. Murrell and N. R. Brereton* 1111

Shale–fluid interaction under simulated downhole conditions, and its effect on borehole stability—*F. Remvik and P. Skalle* 1115

Coupled Mechanical and Hydrologic Processes

Review of some poroelastic effects in rock mechanics—*A. H.-D. Cheng, Y. Abousleiman and J.-C. Roegiers* 1119

On the modelling of near tip processes in hydraulic fractures—*The SCR Geomechanics Group* 1127

Pore pressure buildup coefficient in synthetic and natural sandstones—*P. A. Berge, H. F. Wang and B. P. Bonner* 1135

Evaluation of hydraulic underpressures at Wellenberg, Switzerland—*P. Vinard, P. Blümling, J. P. McCord and G. Aristorenas* 1143

Equivalent properties of a jointed Biot material—*W. G. Pariseau* 1151

Coupled permeability and hydrofracture tests to assess the waste-containment properties of fractured anhydrite—*R. L. Beauheim, W. R. Wawersik and R. M. Roberts* 1159

Effective-stress rules for pore-fluid transport in rocks containing two minerals—*J. G. Berryman* 1165

Laboratory measurements of the effective-stress law for carbonate rocks under deformation—*N. R. Warpinski and L. W. Teufel* 1169

Experimental error for permeability and specific storage from pulse decay measurements—*H. F. Wang and D. J. Hart* 1173

A micromechanically consistent poroviscoelasticity theory for rock mechanics applications—*Y. Abousleiman, A. H.-D. Cheng, C. Jiang and J.-C. Roegiers* 1177

Compressibility of porous rocks under different stress conditions—*Z. Zheng* 1181

Rock Mechanics in Reservoir Engineering

Modeling of naturally fractured reservoirs using deformation dependent flow mechanism—*M. Bai, D. Elsworth and J.-C. Roegiers* 1185

Numerical simulation of shear-induced compaction in the Ekofisk reservoir—*L. Chin, R. R. Boade, J. H. Prevost and G. H. Landa* 1193

A study of shale pore pressure change by the salinity of drilling fluid—*C. H. Yew, F. K. Mody and A. H. Hale* 1201

Pore pressure change and compaction in North Sea chalk hydrocarbon reservoirs—*M. Jones and E. Mathiesen* 1205

Overpressures, fluid flow and stress regimes in the Jeanne d'Arc Basin, Canada—*N. A. Yassir and A. L. Rogers* 1209

A model of dynamic confinement during drilling in pressurized boreholes—*J. J. Kollé* 1215

Inversion of surface displacements to monitor *in situ* processes—*M. B. Dusseault, R. A. Bilak and L. Rothenburg* 1219

Permeability reduction due to grain crushing around a perforation—*E. Papamichos, I. Vardoulakis and H. Ouadfel* 1223

Hydraulic Fracturing for Enhanced Recovery

Modelling the propagation and closure of micro-hydraulic fractures—*J. Desroches and M. Thiercelin* 1231

Analysis of crack reopening behavior for hydrofrac stress measurement—*T. Ito and K. Hayashi* 1235

Influence of inelastic rock behaviour in hydraulic fracturing—*P. Papanastasiou and M. Thiercelin* 1241

Improving the performance of open hole stress tools—*M. Thiercelin and J. Desroches* 1249

Effects of chemical solutions on rock fracturing—*M. G. Karfakis and M. Akram* 1253

Theoretical and experimental investigation of rock dilatancy near the tip of a propagating hydraulic fracture—*P. J. van den Hoek, J. T. M. van den Berg and J. Shlyapobersky* 1261

Numerical simulation of 3D hydraulic fracture using Newtonian and power-law fluids—*J. L. Sousa, B. J. Carter and A. R. Ingraffea* 1265

Incremental growth of a shallow hydraulic fracture at a waste remediation site, Oakbrook, Illinois from inversion of elevation changes—*Y. Du, A. Aydin and L. Murdoch* 1273

Numerical Methods

Micromechanics of granular materials—numerical simulation of the effects of heterogeneities—*Z. Liu, L. R. Myer and N. G. W. Cook* 1281

Mechanics of a rock anchor with a penny-shaped basal crack—*A. P. S. Selvadurai* 1285

Elasto-plastic finite element analysis of underground openings using elastic supports—*S. K. Sharan* 1291

Fracture process zone development during hydraulic fracturing—*J.-I. Huang and K. Kim* 1295

Numerical simulation of a compacting reservoir—*A. Abdulraheem, M. Zaman and J.-C. Roegiers* 1299

Numerical simulation of strain-softening and dilation of rock salt—*K. Fuenkajorn and S. Serata* 1303

A new discrete rockbolt element for finite element analysis—*T. F. Cho and C. Lee* 1307

Constitutive Models

Influence of rock joint degradation on hydraulic conductivity—*M. J. Boulon, A. P. S. Selvadurai, H. Benjelloun and B. Feuga* 1311

Incremental constitutive relations for the study of wellbore failure—*M. Brignoli and L. Sartori* 1319

Deformation and diffusion behaviour in a solid experiencing damage: a continuous damage model and its numerical implementation—*H. Cheng and M. B. Dusseault* 1323

Modeling large underground experimental halls for the superconducting super collider—*F. Duan and M. Mrugala* 1333

Experimental evaluation of a constitutive model for inelastic flow and damage evolution in solids subjected to triaxial compression—*A. F. Fossum, N. S. Brodsky, K. S. Chan and D. E. Munson* 1341

Two- and three-dimensional calculations of scaled *in situ* tests using the M-D model of salt creep—*D. E. Munson, J. R. Weatherby and K. L. DeVries* 1345

Micromechanical modeling of tuffaceous rock for application in nuclear waste storage—*R. Wang and J. M. Kemeny* 1351

Scaling of constitutive parameters of friction for fractal surfaces—*W. Wang and C. H. Scholz* 1359

Stress-induced anisotropy and loading path effects on borehole responses—*Y. Wang, N. Kessler and F. J. Santarelli* 1367

Modeling in Underground Mining

Constraining numerical models with geomechanical data and microseismic fault-plane solutions—*C. F. Connors, T. I. Urbancic, W. F. Bawden and R. P. Young* 1371

A new approach for rock mass cavability modeling—*F. H. Hassen, L. Spinnler and J. Fine* 1379

Geotechnical applications of a two-dimensional elastodynamic displacement discontinuity method—*E. Siebrits and S. L. Crouch* 1387

Case study of monitoring changes in roof stability—*H. Maleki, Y. Jung and K. Hollberg* 1395

Numerical modelling as an aid to the determination of the stress distribution in the goaf due to longwall coal mining—*I. G. T. Thin, R. J. Pine and R. Trueman* 1403

Analysis of a mine roof using the DDA method—*M. R. Yeung* 1411

A numerical approach to subsidence prediction and stress analysis in coal mining using a laminated model—*G. Yang, Y. P. Chugh, Z. Yu and M. D. G. Salamon* 1419

Analysis of preferential flow paths using graph theory—*G. Yang, N. G. W. Cook and L. R. Myer* 1423

Coal and Metal Mining and Ground Control

Field evaluation of cable bolt supports—*J. M. Goris, L. A. Martin and T. M. Brady* 1431

Seismic imaging of blast damage—*S. C. Maxwell and R. P. Young* 1435

A study of ground behavior in longwall mining through field instrumentation—*Z. Yu, Y. P. Chugh, P. E. Miller and G. Yang* 1441

Numerical modeling of ground subsidence due to mining—*Y. Najjar and M. Zaman* 1445

Rock Mechanics in Tunneling

Performance of tunnel portals in weathered rock—*L. W. Abramson, W. H. Hansmire and G. M. Boyce* 1449

Time dependent behavior of tunnels excavated in porous mass—*A. Giraud, J. M. Picard and G. Rousset* 1453

Large diameter tunneling in a soft clay shale—a case history of the San Antonio Flood Control Tunnels—*M. G. Green and W. A. Wallace* 1461

Influence of a strengthened rock ring on the deformations of the opening for a deep tunnel—*H. Hagedorn and G. Sattel* 1469

Soft rock tunneling conditions and concerns in downtown Minneapolis—*E. N. Lindner* 1473

Design and construction of a wide tunnel under shallow cover—the Lafayette Bluff tunnel south portal—*D. L. Petersen and C. R. Nelson* 1477

Tunneling under the Apache Trail—*G. A. Scott and J. T. Kottenstette* 1485

Performance of roadheaders at Harlan, KY, diversion tunnels—*M. D. Simmons* 1491

Some modes of deformation and failure of lined tunnels—*F. S. Kendorski* 1497

Large Underground Facilities

In situ flow testing of a cement borehole seal in welded tuff—*D. R. Crouthamel, K. Fuenkajorn and J. J. K. Daemen* 1503

The influence of strain rate and sample inhomogeneity on the moduli and strength of welded tuff—*R. J. Martin III, R. H. Price, P. J. Boyd and J. S. Noel* 1507

Detailed measurements of deformation in the excavation disturbed zone—*P. M. Thompson, J. B. Martino and M. H. Spinney* 1511

Gas barrier design for the WIPP—*F. D. Hansen, M. J. Leroch, L. Van Sambeek and M. S. Lin* 1515

3D structural analysis of SPDV Test Room 2 and cross drift intersections at the WIPP—*J. G. Augüello* 1519

Evaluating the effects of the number of caverns on the performance of underground oil storage facilities—*E. L. Hoffman and B. L. Ehgartner* 1523

Rock Mechanics of Building Stones and Quarries

Variations of rock properties within a quarry—*J. M. Logan, M. Hastedt, D. Lehnert and M. Denton* 1527

A case study of the properties of marble as building veneer—*J. M. Logan, M. Hastedt, D. Lehnert and M. Denton* 1531

Experimental and analytical interpretation of the behaviour of laboratory tests on composite specimens—*O. Del Greco, A. M. Ferrero and C. Oggeri* 1539

Long term stability of the underground cavern for the Pharaoh and the deterioration of the Great Sphinx—*C. Tanimoto, S. Yoshimura and J. Kondo* 1545

Cracks in building stone—*G. Simmons and D. Richter* 1553

Accelerated weathering in building stone—*S. Bortz, J. Stecich, B. Wonneberger and I. Chin* 1559

Use of physical property data and testing in the design of curtain wall—*J. A. Bayer and C. D. Clift* 1563

Structural analysis of stone clad precast concrete building panels—*K. R. Hoigard, R. W. Kritzler and G. R. Mulholland* 1567

Block Theory

The influence of water on the behaviour of a key block—*M. Karaca and R. E. Goodman* 1575

Stability analysis of multiple-block sliding surfaces—*C. F. Leung and K. W. Lo* 1579

Variation of joint orientation in block theory analysis—*M. Mauldon* 1585

The block failure likelihood: a contribution to rock engineering in blocky rock masses—*Y. Hatzor* 1591

Computing 3-D key blocks delimited by joint traces on tunnel surfaces—*J. C. Chern and M. T. Wang* 1599

Stochastic Methods in Rock Engineering

Study of transient flow in hard fractured rocks with a discrete fracture network model—*S. Ezzedine and G. de Marsily* 1605

Stochastic estimation of fracture size through simulated sampling—*P. R. La Pointe, P. C. Wallmann and W. S. Dershowitz* 1611

A zeroth-order statistical model for fracture in rock in compression—*S. C. Blair, N. G. W. Cook and S. Daveler* 1619

Probabilistic slope analysis for structural failure—*D. S. Young* 1623

Spatial simulation of rock strength properties using a Markov–Bayes method—*S. M. Miller and R. D. Luark* 1631

AUTHOR INDEX

Abdulraheem A., 1299
Abel J. F. Jr, 93
Abousleiman Y., 1119, 1177
Abramson L. W., 1449
Addis M. A., 1027
Ahola M. P., 825
Akram M., 1253
Al-Samahiji D., 157
Amadei B., 747, 1005
Aoki T., 1031
Aritorenas G., 1143
Augüello J. G., 1519
Auzerais F., 1091
Ayari M. L., 873
Ayday C., 322
Aydin A., 1273

Bai M., 1185
Bamford W. E., 1031
Bawden W. F., 1371
Bayer J. A., 1563
Beauheim R. L., 1159
Benjelloun H., 1311
Berckhemer H., 331
van den Berg J. T. M., 1261
Berge P. A., 1135
Berryman J. G., 1165
Bilak R. A., 1219
Blair S. C., 1619
Blümling P., 1143
Boade R. R., 1193
Bonner B. P., 699, 755, 1135
Boone T. J., 322
Bortz S., 1559
Boulon M. J., 1311
Bovberg C., 677
Boyce G. M., 1449
Boyd P. J., 1507
Bozdağ T., 443
Brady B. T., 913
Brady T. M., 1431
Brereton N. R., 1111
Bridell J. M., 451
Brignoli M., 1319
Brodsky N. S., 1341
Brown S. R., 845
Brudy M., 1035
Bruno M., 677
Burton P. W., 1009
Butenuth C., 157
Butterworth S., 1009

Cai M., 351
Carlson S. R., 901
Carroll R. D., 559, 575
Carter B. J., 1265
Chan H. C. M., 141
Chan K. S., 1341
Chandler N., 959
Chandler N. A., 989, 993
Cheatham J. B. Jr, 1095
Chen W.-Y., 779
Chenevert M. E., 703
Cheng A. H.-D., 1119, 1177
Cheng H., 1323
Chern J. C., 1599
Chin I., 1559
Chin L., 1193
Cho T. F., 1307
Chowdhury A. H., 825
Christensen N. I., 751
Chugh Y. P., 1419, 1441
Clift C. D., 1563
Connors C. F., 1371
Cook J. M., 1091
Cook N. G. W., 785, 1281, 1423, 1619
Cools P. M. C. B. M., 25
Cornet F. H., 789
Corthésy R., 395
Cosgrove J. W., 157
Coughlin J. P., 917
Cowgill S. M., 1111
Cox S. J. D., 11
Cristescu N. D., 125
Crouch S. L., 1387
Crouthamel D. R., 1503
Cuisiat F. D. E., 1077
Curran J. H., 591
Cuxac P., 527

Daemen J. J. K., 1503
Das B. M., 711
Dass R. N., 711
Daveler S, 1619
Del Greco O., 1539
Denton M., 1527, 1531
Dershowitz W. S., 1611
Desroches J., 1231, 1249
Detournay E., 322
Devries K. L., 1345
Dick R. D., 413
Diederichs M. S., 163
Dintaman C., 687
Douglas B. J., 687
Du W., 809
Du Y., 1273
Duan F., 1333
Dunning J., 687
Durham W. B., 699
Dusseault M. B., 1219, 1323
Dwarakanath V., 703
Dyskin A. V., 813

Ehgartner B. L., 1523
Elsworth D., 71, 1185
Ewy R. T., 1061
Ezzedine S., 1605

Felice C. W., 669
Ferrero A. M., 1539
Feuga B., 1311
Fine J., 1379
Fjær E., 1085
Fossum A. F., 1341
Fourney W. L., 413
Fowell R. J., 821, 821
Franklin J. A., 37
Fredrich J. T., 669, 691
de Freitas M. H., 157
Fuenkajorn K., 1303, 1503
Fukui K., 257

Germanovich L. N., 813
Ghosh A., 825
Gill D. E., 219, 395
Giraud A., 1453
Göktan R. M., 322
Goldsmith G., 1091
Goodman R. E., 1575
Gordeyev Yu. N., 233
Goris J. M., 1431
Grabinsky M. W. F., 591
Grasso P., 567
Gray K. E., 771, 831
Greaves K. H., 691
Green D. H., 755
Green M. G., 1461
Green S. J., 669
Guangxu T., 473
Guo F., 177, 189, 203, 617, 627

Hack H. R. G. K., 151
Hagedorn H., 1469
Haimson B. C., 271, 289, 959, 1039, 1047
Hale A. H., 1201
Haley G. M., 779
Hammade E., 527
Hanna K., 913
Hansen F. D., 735, 1515
Hansen S. E., 977, 1001
Hansmire W. H., 1449
Hareland G., 715
Hart D. J., 1173
Hart P. A., 247
Hashida T., 47, 61
Hassani F. P., 321
Hassen F. H., 1379
Hastedt M., 1527, 1531
Hatzor Y., 1591
Hayashi K., 951, 1235
Hencher S. R., 81
Henry J.-P., 527
Hillis R. R., 1103
Hingira J., 151
Hirasawa T., 551
van den Hoek P. J., 1261
Hoffman E. L., 1523
Hoigard K. R., 1567
Holcomb D. J., 929
Holder J., 771, 831
Hollberg K., 1395
Holt R. M., 719
Homand F., 527
Horii H., 351
Hsiung S. M., 825
Hu K. X., 381
Hualin G., 473
Huang J., 643, 877, 925
Huang J.-I., 1295
Huang X., 271, 289
Huang Y., 381
Hudson J. A., 457, 1077
Hudson J. L., 457

Ibanez W. D., 723
Iihoshi S., 853
Ikeda R., 1013
Ingraffea A. R., 1265
Inyang H. I., 707
Ishida T., 909
Ita S. L., 785
Ito T., 951, 1235

Jiang C., 1177
Johnston J. E., 751
Jones M., 1205
Jones M. E., 739
Jung Y., 1395

Kågeson-Loe N. M., 739
Karaca M., 1575
Karfakis M. G., 1253
Kato N., 551
Kazakidis V. N., 163
Kemeny J. M., 809, 1351
Kendorski F. S., 1497
Kenter C. J., 719
Kessler N., 1085, 1367
Khan A. R., 747
Kikuchi S., 981
Kim K., 1295
Klee G., 973
Kobayashi H., 909
Kollé J. J., 1215
Kondo J., 1545
Kottenstette J. T., 1485
Kristiansen J., 977
Kritzler R. W., 1567
Kronenberg A. K., 723
Kulatilake P. H. S. W., 479, 503
Kuriyama K., 111
Kusunose K., 1

La Pointe P. R., 1611
LaComb J. W., 575
Labuz J. F., 451
Ladanyi B., 219, 573
Lajtai E. Z., 873
Landa G. H., 1193
Leddra M. J., 739
Lee C., 1307
Lee M., 959, 1039
Lehnert D., 1527, 1531
Leite M. H., 219, 395
Leroch M. J., 1515
Leung C. F., 1579
Li C., 943, 601
Li Y., 985
Liang Z., 545
Lin D., 841
Lin M. S., 1515
Lindner E. N., 1473
Liu Z., 1281
Lo K. W., 1579
Lockner D., 883
Logan J. M., 1527, 1531
Lovell C. W., 779
Luark R. D., 1631
Lumsden A. C., 81

Ma Q., 763
Maleki H., 1395
Manolopoulou S., 81
de Marsily, 1605
Martin C. D., 797, 993
Martin D., 959
Martin III R. J., 1507
Martin J. W., 669, 691
Martin L. A., 1431
Martino J. B., 1511
Masuda K., 1
Mathiesen E., 1205
Matsuki K., 1019
Matsunaga I., 909, 1023
Mauldon M., 1585
Mavko G., 805
Maxwell S. C., 1435
McCord J. P., 1143
McDonald S. K., 687
McNearny R. L., 93
Meredith P. G., 11, 937, 1111
Miller P. E., 1441
Miller S. M., 1631
Mishnaevsky L. L. Jr, 663
Mizuta Y., 111, 981
Mlakar V., 321
Mody F. K., 1201
Moelle K. H. R., 601
Momayez M., 321
Moos D., 965
Morel E., 527

Morgenstern N. R., 177, 189, 203, 617, 627
Morita N., 1085
Mottahed P., 857
Mrugala M., 1333
Mulder A., 659
Mulholland G. R., 1567
Munson D. E., 1341, 1345
van Munster J. G., 937
Murdoch L., 1273
Murrell S. A. F., 937, 1111
Myer L. R., 785, 1281, 1423
Myrvang A., 1001

Nagahama H., 173, 469
Najjar Y., 1445
Nelson C. R., 1477
Nihei K. T., 785
Nishimatsu Y., 257
Nishizawa O., 1
Noel J. S., 1507
Nordlund E., 943
Nur A., 805

Oggeri C., 1539
Oikawa Y., 1023
Okubo S., 257
Olsson W. A., 845
Ong S. H., 1069
Ouadfel H., 1223
Ouyang Z., 71

Pan E., 1005
Papaliangas T., 81
Papamichos E., 1223
Papanastasiou P., 1241
Pariseau W. G., 343, 1151
Park H. D., 157
Paşamehmetoğlu A. G., 443
Passaris E. K. S., 857
Petersen D. L., 1477
Petley D. N., 739
Picard J. M., 1453
Pine R. J., 1403
Pitt J. M., 707
Plesha M. E., 271, 289
Pollard D. D., 869
Polston C. E., 715
Prevost J. H., 1193
Price R. H., 1507
Puri V. K., 711
Pyrak-Nolte L. J., 779

Qiu X., 271, 289

Rabajoli G., 567
Ran J. Q., 857
Ratigan J. L., 735
Reddish D. J., 431
Reed M. B., 567
Remvik F., 1115
Richter D., 1553
Rizzi D., 567
Roberts R. M., 1159
Roegiers J.-C., 763, 837, 841, 1069, 1119, 1177, 1185, 1299
Rogers A. L., 1209
Rothenburg L., 1219
Rousset G., 1453
Rowell G. A., 917
Rummel F., 973

Salamon M. D. G., 1419
Santarelli F. J., 1085, 1367
Sartori L., 1319
Sasaki S., 909
Satoh T., 1
Sattell G., 1469
Savage W. Z., 325
Schetelig K., 157
Schmitt D. R., 305, 985, 1057
Scholz C. H., 1359
Scott G. A., 1485
Scott J. D., 177, 189, 203, 617, 627
Scott T. E. Jr, 763
Scotti O., 789
Selvadurai A. P. S., 1285, 1311
Şen Z., 555
Serata S., 1303
Sharan S. K., 1291
Shen B., 861
Shimo M., 853
Shlyapobersky J., 1261
Siebrits E., 1387
Sijing C., 473
Simmons G., 1553
Simmons M. D., 1491
Skalle P., 1115
Song D., 653
Song I., 1047
Sørensen T., 1001
Sousa J. L., 1265
Spann H., 1057
Spinney M. H., 1511
Spinnler L., 1379
Stecich J., 1559
Steiger R. P., 681
Steiner W., 361
Stephansson O., 479, 503, 861
Stuart C. E., 937

Tait R. J., 1057
Takahashi H., 47
Takeuchi K., 1019
Tan C. P., 1031, 1103
Tanimoto C., 1545
Teufel L. W., 1169
Thallak S., 771, 831
Thiercelin M., 1231, 1241, 1249
Thin I. G. T., 1403
Thompson P. M., 1511
Tokunaga K., 981
Tronvoll J., 1085
Trueman R., 1403
Tso C. P., 633
Tunbridge L. W., 977

Unander T. E., 719, 947
Urbancic T. I., 1371

Van Sambeek L. L., 735, 1515
Vardoulakis I., 1223
Vernik L., 677
Verwaal W., 151, 659
Vinard P., 1143

Wallace W. A., 1461
Wallmann P. C., 1611
Wand H. F., 755, 1135, 1173
Wang M. T., 1599
Wang P., 537
Wang R., 643, 877, 1351
Wang S., 479
Wang W., 1359
Wang X. J., 413
Wang Y., 1367
Wang Z., 925
Warpinski N. R., 1169
Wathugala D. N., 503
Wawersik W. R., 1159
Weatherby J. R., 1345
Wei Y., 413
White W. E., 715
Whittaker B. N., 431
Willoughby D. R., 1103
Wonneberger B., 1559
Wright M. A., 711
Wu B., 1027
Wu H., 869

Xie H., 343
Xu C., 821
Xu J., 545

Yamaguchi T., 1023
Yamamoto H., 551
Yamamoto K., 551
Yang G., 1419, 1423, 1441
Yao X. L., 431
Yassir N. A., 1209
Yen S. C., 711
Yeşil M. M., 443
Yeung M. R., 1411
Yew C. H., 1201
Yin H., 805
Yoshii K., 173
Yoshimura S., 1545
Young D. S., 1623
Young R. P., 797, 901, 1371, 1435
Younus M. J., 771
Yu Z., 1419, 1441
Yuan Y. G., 873

Zaman M., 1299, 1445
Zang A., 331
Zhang L., 37
Zhao J., 633
Zhao X. L., 837
Zhao Y., 643, 877, 925
Zheng Z., 1181
Zhou S., 1103
Zhu W., 537, 545
Zoback M. D., 305, 965, 1035

Typeset in Great Britain by BPCC Techset Ltd, Exeter. Printed by BPCC Wheatons Ltd, Exeter